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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE ~~CONFIDENTIAL~~ REPORT

DRAG MEASUREMENTS AT TRANSONIC SPEEDS ON A FREELY FALLING BODY

By F. J. Bailey, Jr., Charles W. Mathews and Jim Rogers Thompson

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SUMMARY

Direct measurements have been made of the drag of a special test body and its stabilizing tail surfaces throughout free drops from high altitudes. The data obtained have been used to establish the relation between the drag coefficient and the Mach number for the body and for the tail surfaces over a range of Mach numbers from 0.85 to 1.15.

For bodies of the form tested, the drag per square foot of frontal area increased abruptly from about 3 percent of atmospheric pressure at a Mach number of 0.95 to 17 percent of atmospheric pressure at a Mach number of 1.00, then linearly with Mach number to 28 percent of atmospheric pressure at a Mach number of approximately 1.15.

Some doubt exists as to the applicability of the tail drag results to the estimation of wing drag at transonic speeds because of the possibility of appreciable interference effects between the vertical and the horizontal surfaces and between the body and the tail surfaces. Insofar as they are applicable, the tail drag results indicated that with symmetrical 6-percent-thick NACA 16-series wings the drag per square foot of frontal area may be expected to increase abruptly from 4 percent of atmospheric pressure at a Mach number of 0.88 to 36 percent of atmospheric pressure at a Mach number of 1.00, then linearly with Mach number to approximately 50 percent of atmospheric pressure at a Mach number of 1.15.

INTRODUCTION

Recent developments in radar, phototheodolite, and radio-telemeter equipment have made it possible to measure the drag of aerodynamic shapes at transonic speeds attained in free drops from high altitudes. Tests of the first of a series of bodies to be studied in this way have recently been completed. The results of these tests are presented herein as separate curves of drag coefficient plotted against Mach number for the body and for its stabilizing tail surfaces.

APPARATUS AND METHOD

Test bodies.- The details of the test shape and its tail surfaces are given in figure 1. This particular body shape was selected as representative of designs that might be expected to have comparatively low drag at transonic speeds. Since the tests were planned to be primarily a study of body drag at the highest attainable speeds, the tail arrangement was designed to provide adequate stability and have a drag that would be small relative to the drag of the body.

Six bodies of this shape were dropped from an altitude of approximately 35,000 feet. These bodies were identical externally but varied in weight and method of construction. The two heavier bodies were made of metal, carried radio-telemeter equipment, and weighed 445 and 447 pounds. The four lighter bodies were made of wood and carried no measuring instruments, telemetering equipment, or radio antenna. The lighter bodies weighed 96, 100, 187, and 197 pounds.

Measurements.- For the telemeter-equipped bodies, the total drag of the body and tail was obtained directly from the telemetered reading of a sensitive accelerometer that was alined with the axis of the body. The drag of the tail surfaces was determined from telemetered measurement of the longitudinal reaction between these surfaces and the cylindrical boom that supported them. The speed of the body at any instant was obtained both by step-by-step integration of the accelerations imposed on the body and by differentiation of a time history of the flight path as measured with radar and phototheodolite

equipment. Evidence that the body did not oscillate in yaw relative to its flight path was provided by telemetered differential pressures between orifices on opposite sides of the body at its maximum thickness and by telescopic observations of the body from the ground.

For the four wooden bodies without telemetering equipment, the speeds and a limited amount of information on the total drags were obtained from the radar and phototheodolite measurements.

Information on atmospheric pressures and temperatures at the various heights was obtained from synchronized altimeter, thermometer, radar, and phototheodolite readings taken during the climb and descent of the airplane from which the bodies were dropped.

Reduction of data.- In the reduction of the data for the telemeter-equipped bodies, the directly measured values of the drag D, the static pressure p, the speed V, the temperature T, and the frontal area F were combined to produce time histories of the nondimensional ratio D/Fp and the Mach number M. Values of the conventional drag coefficient C_D based on frontal area were then obtained from these curves by substitution in the relation

$$C_D = \frac{D/Fp}{\frac{\gamma}{2} M^2} \tag{1}$$

where the specific-heat ratio γ was taken as 1.4. For the tail surfaces, these values of C_D were multiplied by the thickness ratio to convert them to drag coefficients based on plan area. The frontal and plan areas used in the computation of the tail drag coefficients did not include the area within the tail extension shaft or the area removed in rounding the tips. No allowance was made for the effect of the wake of the body on the tail drag.

For the bodies without instruments, values of the total drag at the highest Mach numbers reached were obtained from the relation

$$D = W\left[-\frac{1}{(\gamma R)^{1/2}T^{1/2}M}\frac{dh}{dt} - \frac{(\gamma R)^{1/2}M}{2gT^{1/2}}\frac{dT}{dt} - \frac{(\gamma R)^{1/2}T^{1/2}}{g}\frac{dM}{dt}\right] \qquad (2)$$

where

W weight of body, pounds

h height of body above ground at time t, feet

g acceleration of gravity $(32.2\ \mathrm{ft/sec^2})$

R gas constant for air $(1716\ \mathrm{ft\text{-}lb/slug/^\circ F})$

RESULTS AND DISCUSSION

Time histories of the pertinent measured and computed quantities for the two bodies equipped with radio telemeters are given in figures 2 and 3. The differential-pressure data are not included in these figures because examination of the records showed no oscillations and confirmed the statements of ground observers that all bodies remained steady throughout the drops.

A check on the over-all accuracy of the test results is provided by the comparison in figure 4 of the velocity-altitude data obtained from the radar and phototheodolite equipment with similar data obtained from step-by-step integration of the telemetered accelerations imposed on the body.

Time histories for the bodies without instruments are given in figures 5 and 6. The apparent fluctuations in velocity in the records for the 96-, 187-, and 197-pound bodies resulted primarily from the inability of the operator to keep the axis of the phototheodolite equipment pointed continuously at the body. The photographs that normally permit correction for these small errors in pointing were not obtained during the drops of these particular bodies. The velocity fluctuations that appear in figure 4(b) during the last part of the drop of the 445-pound body (body 3) have a similar explanation.

The precision with which the time derivative of Mach number dM/dt was established for the bodies without instruments generally was not sufficient to

warrant use of equation (2) and the time histories to determine the variation of total drag with Mach number throughout each drop. There are periods in each drop, however, during which the Mach number appears to remain approximately constant for a sufficient length of time to warrant calculations of the total drag at these Mach numbers. Although the drag values calculated in this manner are not expected to be so precise as those obtained from the telemetered accelerations, these drag values do provide an independent check on the order of magnitude of the drag rise. These drag values have been calculated and the corresponding values of the ratio D/Fp have been plotted in figure 7 for comparison with a curve representing an average of the values obtained for the two telemeter-equipped bodies.

The body and tail drag data from the tests of the bodies with instruments are summarized in figure 8, in which average values of D/Fp and C_D for the two bodies and for their tail surfaces are plotted against Mach number. The deviation of the curve of C_D against M for each of the two bodies from the average curve shown is no more than 0.01 in C_D or D/Fp and no more than 0.005 in Mach number. Because of the interest in the relative drag of wings and bodies, the coefficients based on frontal area for the tail surfaces have been plotted to the same scale as the body coefficients. In the examination and use of these curves, it should be kept in mind that, because of the smaller forces involved, the error in the values of the tail coefficients may be approximately five times as great as in the body coefficients, or about 0.003 in the tail drag coefficient based on plan area.

The data summarized in figure 8 show that, for bodies of the form tested, the drag per square foot of frontal area increased abruptly from about 3 percent of atmospheric pressure at a Mach number of 0.95 to 17 percent of atmospheric pressure at a Mach number of 1.00, then linearly with Mach number to 28 percent of atmospheric pressure at a Mach number of approximately 1.15.

Some doubt exists as to the applicability of the tail drag results to the estimation of wing drag at transonic speeds because of the possibility of appreciable interference effects between the vertical and the horizontal surfaces and between the body and the tail surfaces. Insofar as they are applicable, the tail drag

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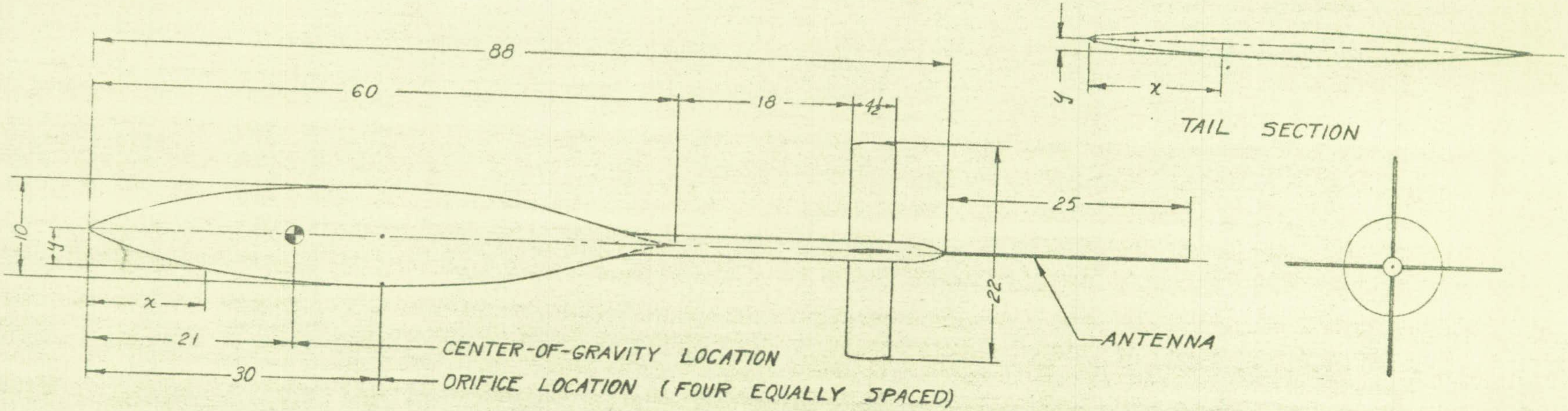

BODY COORDINATES			
x	y	x	y
0.000	0.000	24.000	4.876
0.300	0.277	27.000	4.971
0.450	0.358	30.000	5.000
0.750	0.514	33.000	4.955
1.500	0.866	36.000	4.828
3.000	1.446	39.000	4.610
4.500	1.936	42.000	4.274
6.000	2.365	45.000	3.754
9.000	3.112	48.000	3.031
12.000	3.708	51.000	2.222
15.000	4.158	54.000	1.350
18.000	4.489	57.000	0.526
21.000	4.719	60.000	0.000
NOSE RADIUS: 0.060			

BODY	WEIGHT (LB)	TEST DATE	INSTRUMENTATION
1	447	1/29/45	TELEMETER
2	187	1/29/45	NONE
3	445	1/30/45	TELEMETER
4	96	1/30/45	NONE
5	197	1/31/45	NONE
6	100	1/31/45	NONE

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TAIL-SECTION COORDINATES (NACA 16-SERIES AIRFOIL)			
x	y	x	y
0.000	0.000	1.350	0.122
0.052	0.029	1.800	0.132
0.113	0.041	2.250	0.135
0.225	0.056	2.700	0.131
0.338	0.068	3.150	0.118
0.450	0.078	3.600	0.094
0.675	0.093	4.050	0.057
0.900	0.105	4.275	0.032
1.125	0.115	4.500	0.003
L.E. RADIUS: 0.008			

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Figure 1. - General arrangement and dimensions of test body. (All dimensions are in inches.)

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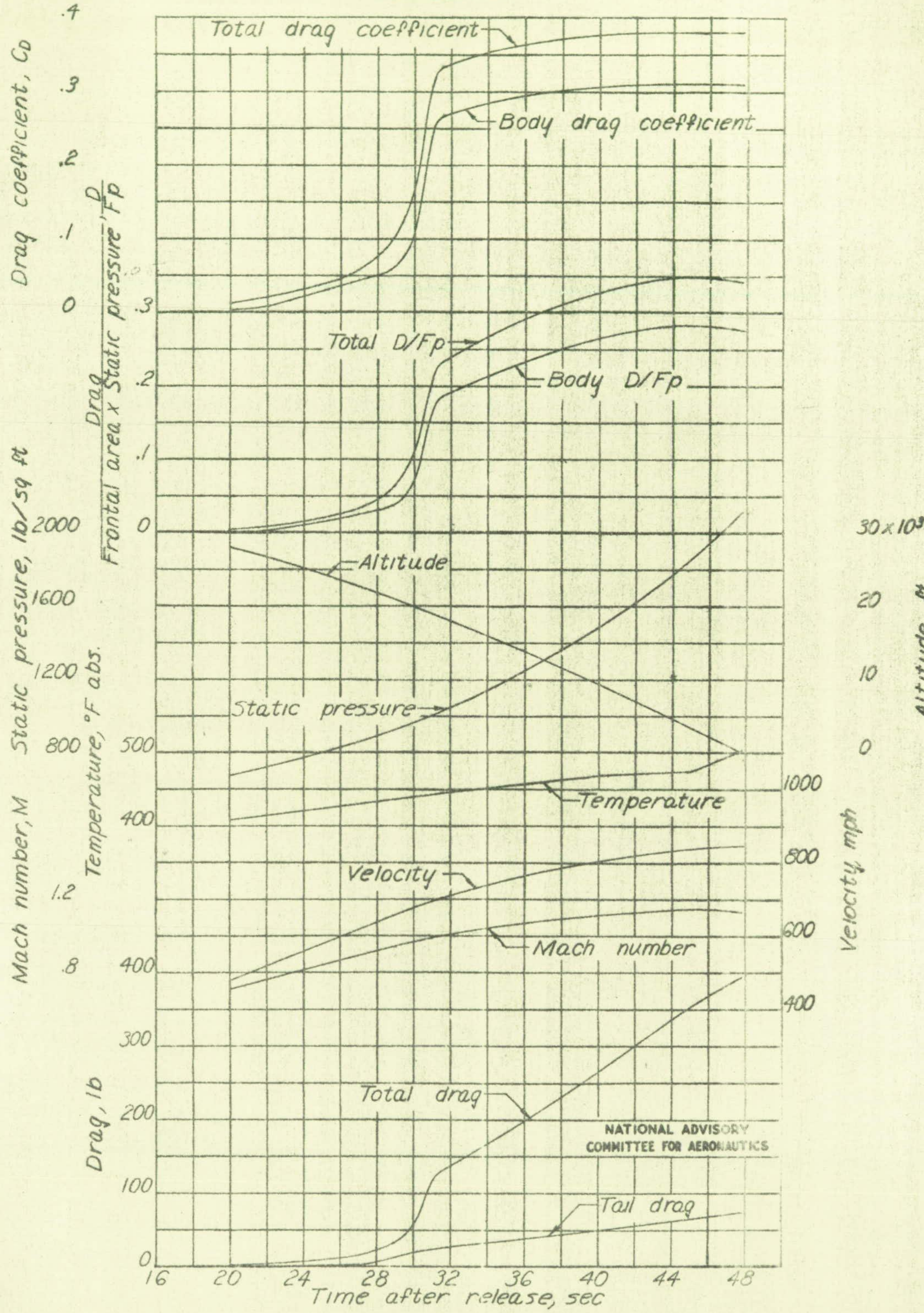

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Figure 2. - Time history of free drop of 447-pound body having radio telemeter (body 1).

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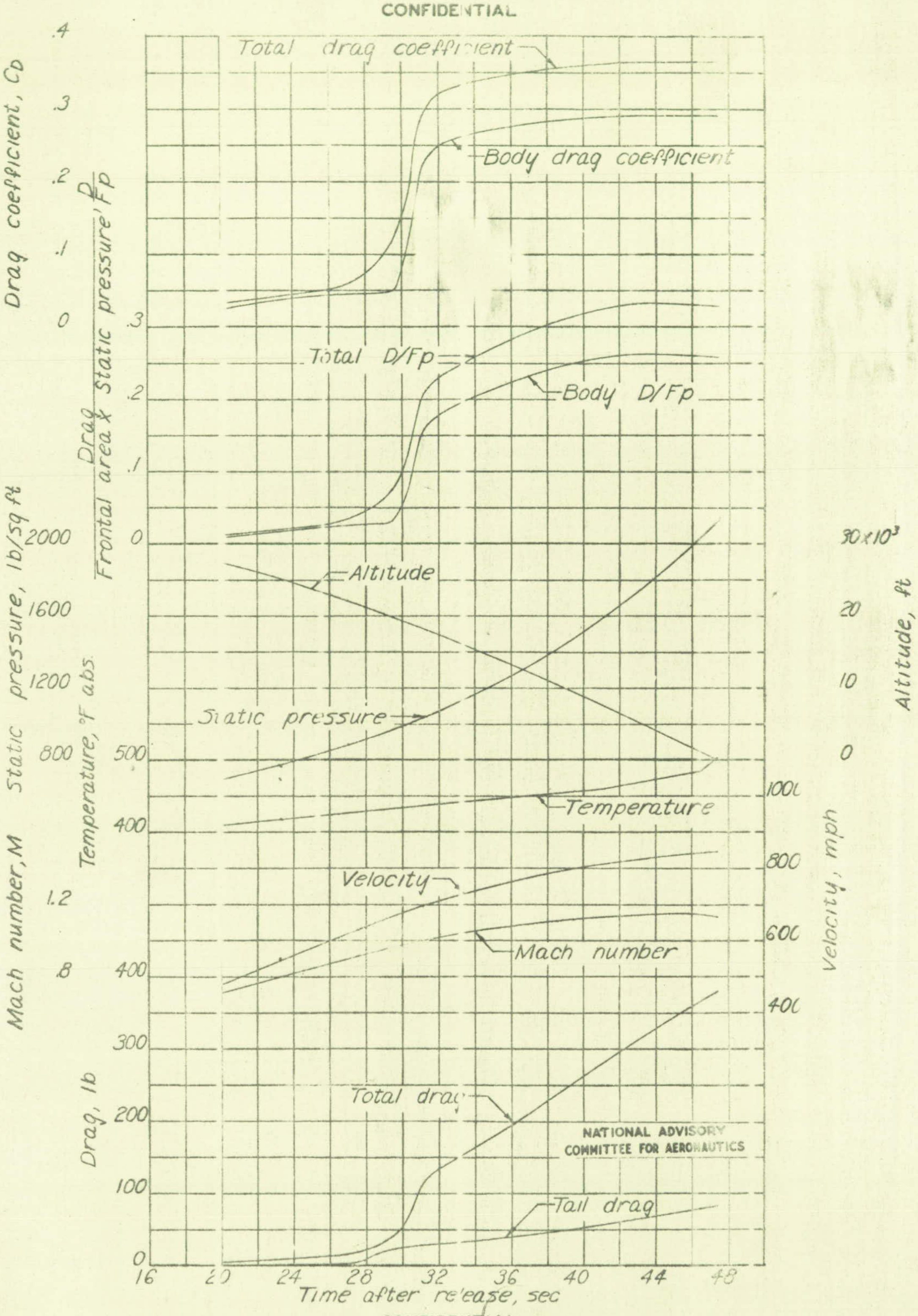

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Figure 3. - Time history of free drop of 445-pound body having radio telemeter (body 3).

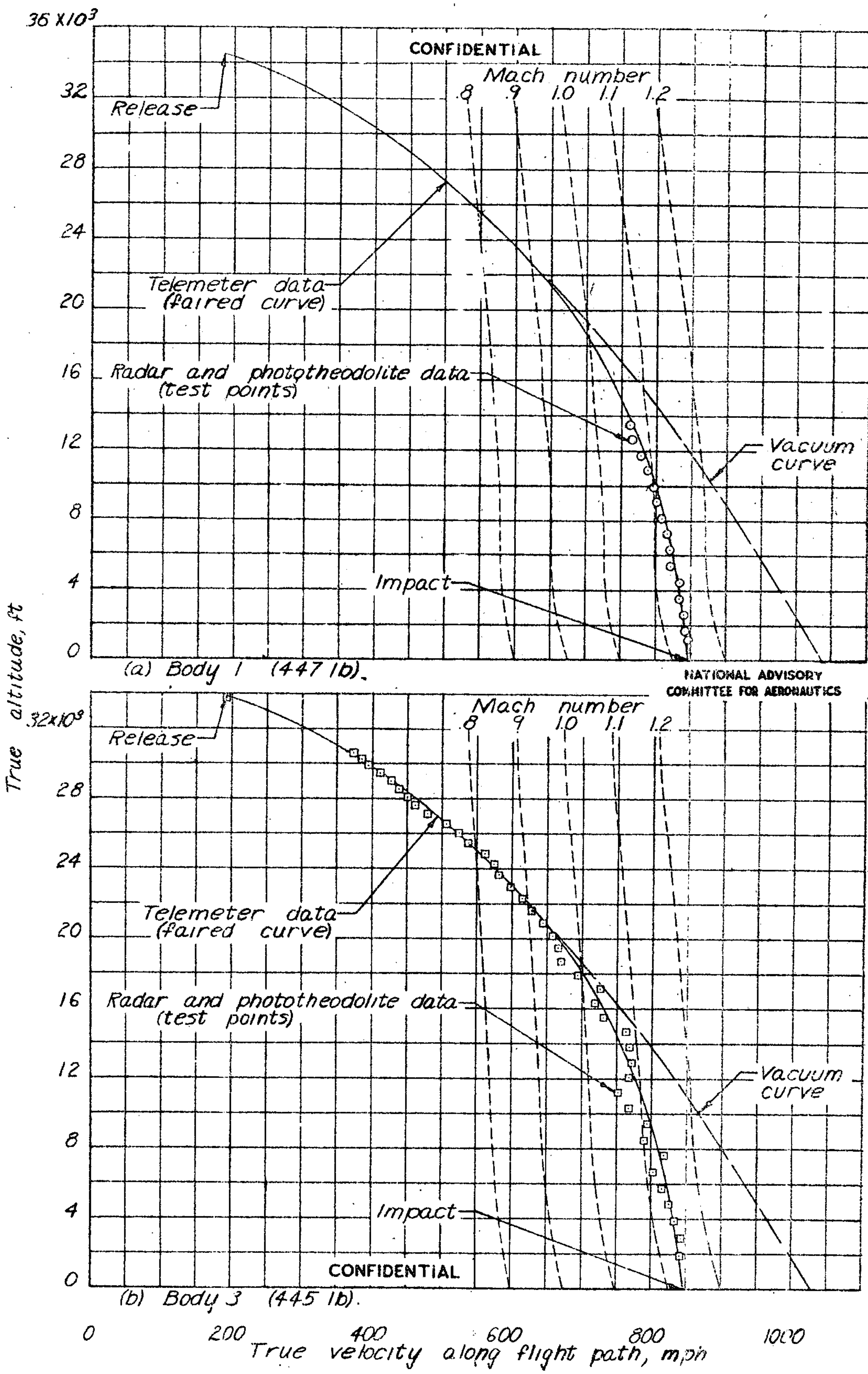

Figure 4. - Comparison of velocity-altitude data obtained from radar and phototheodolite equipment with values obtained from step-by-step integration of telemetered accelerations.

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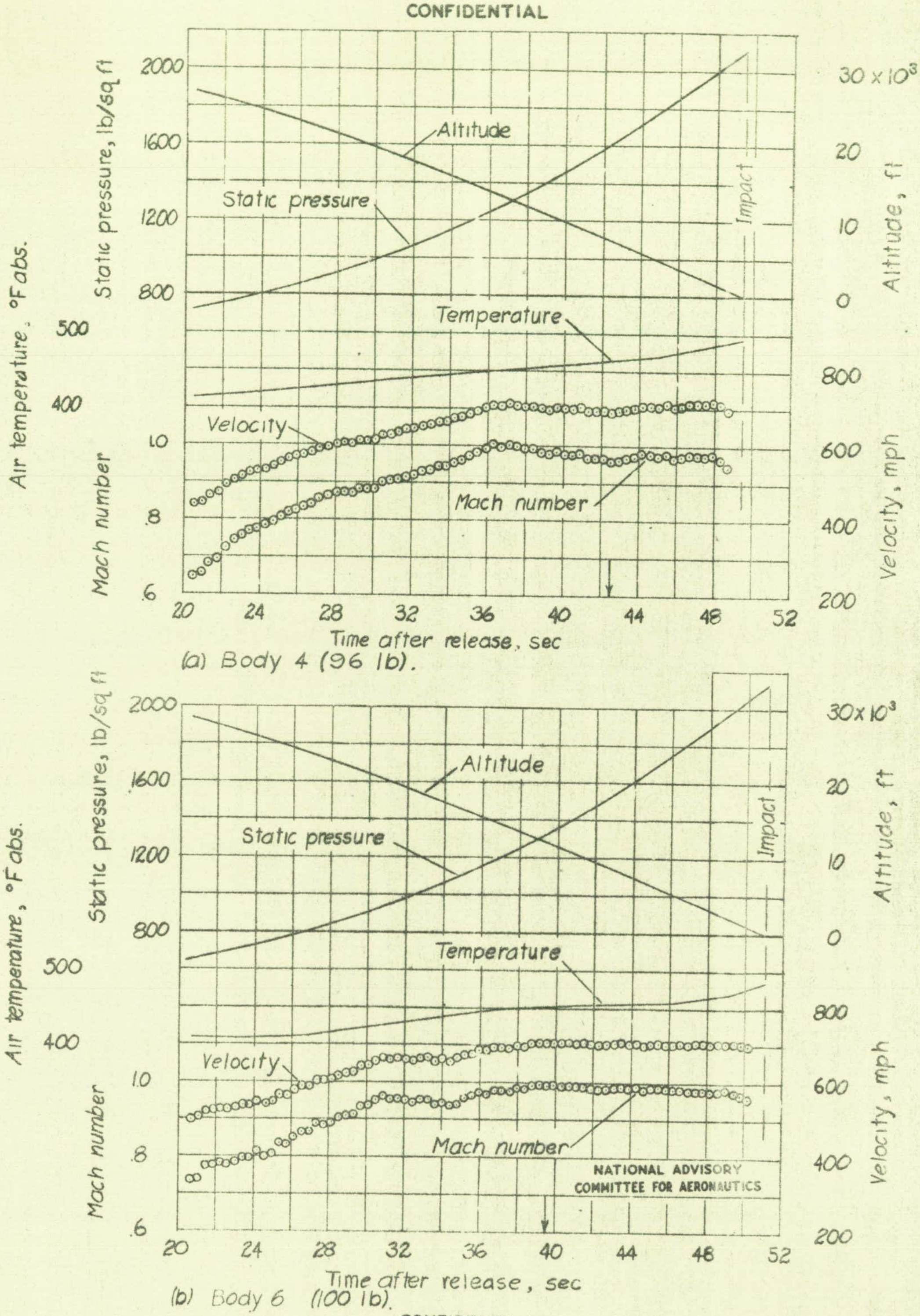

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Figure 5.- Time histories of free drops of 96- and 100-pound test bodies without instruments. (Arrows indicate time at which drag values were calculated.)

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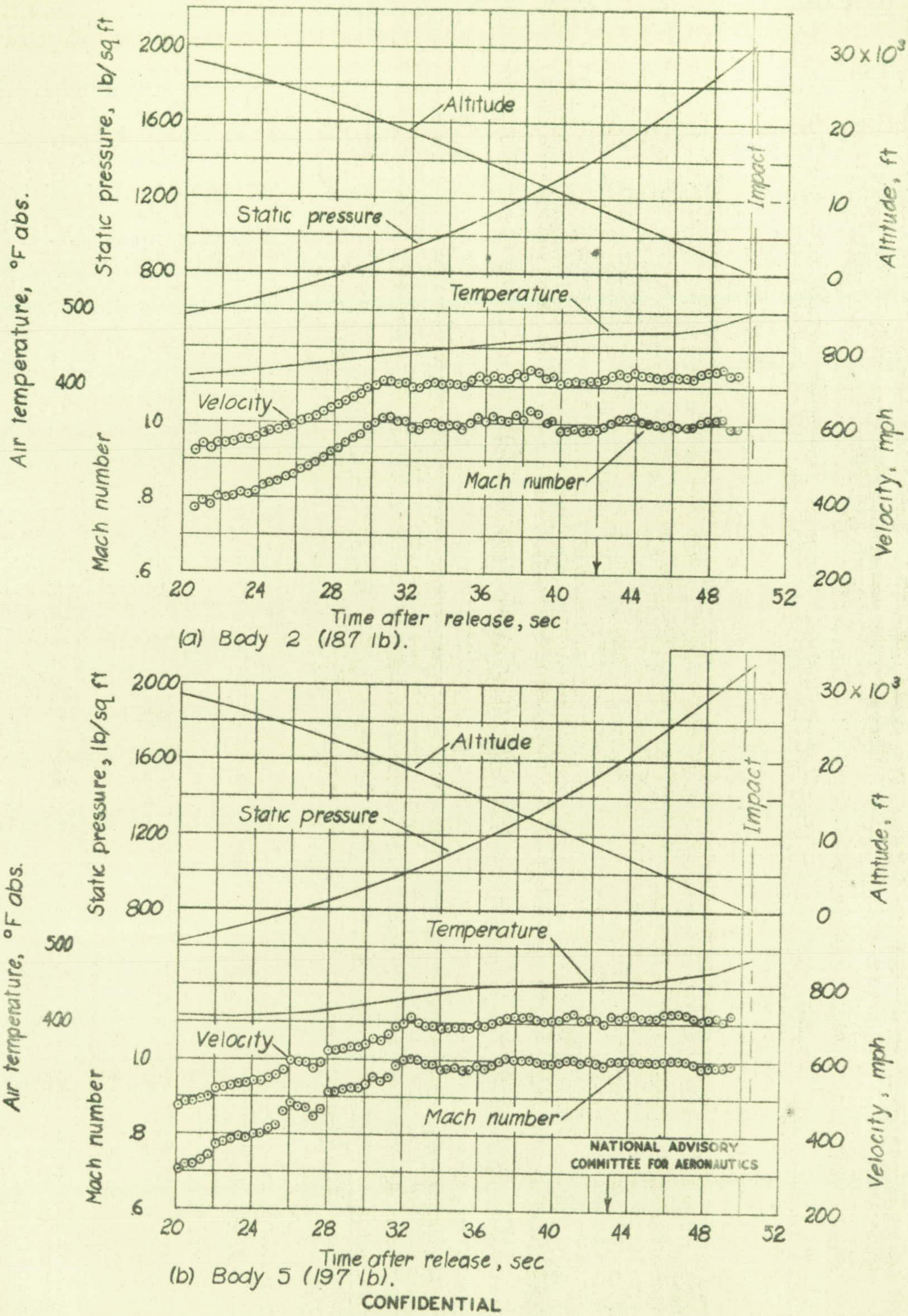

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Figure 6.- Time histories of free drops of 187- and 197-pound test bodies without instruments. (Arrows indicate time at which drag values were calculated.)

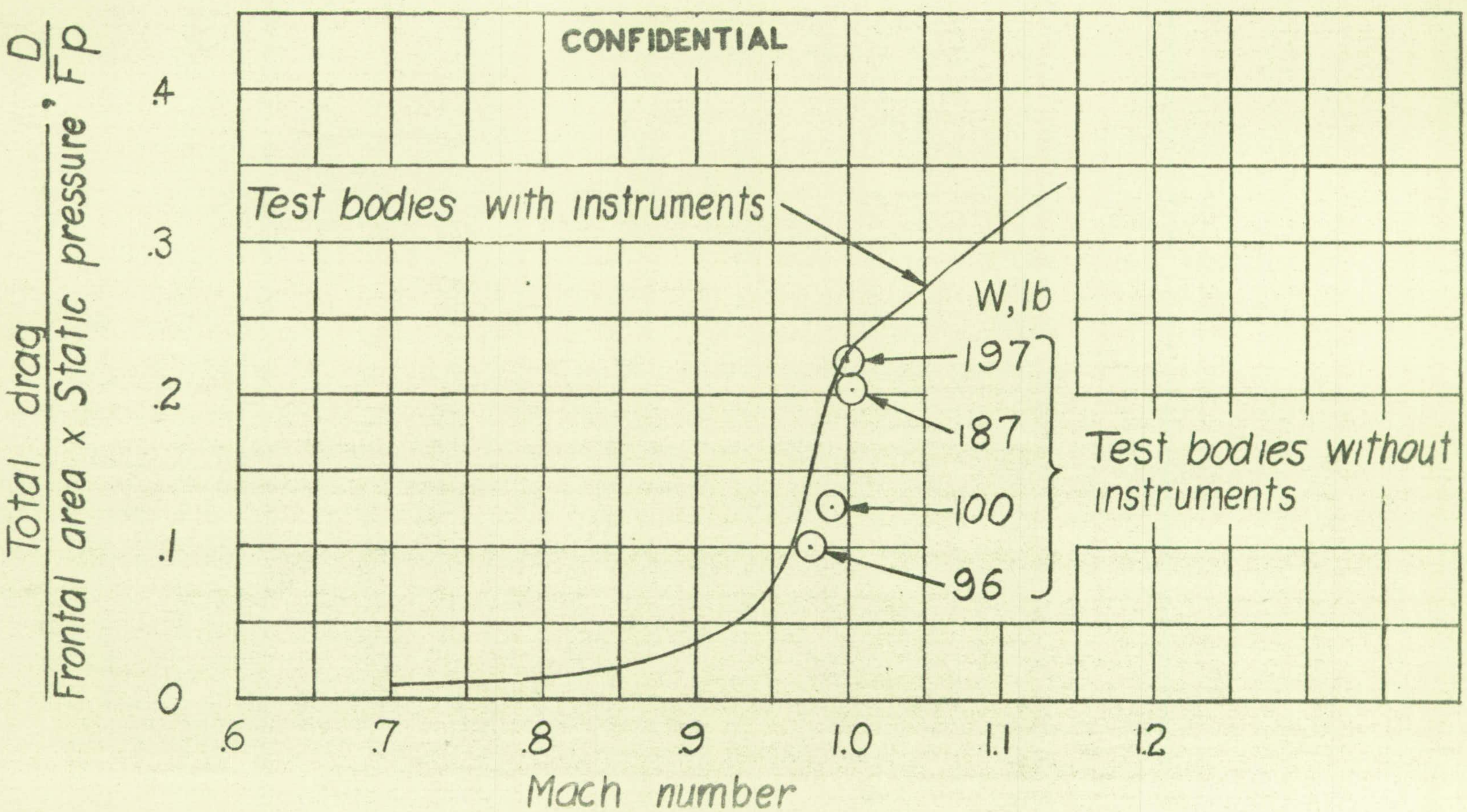

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Figure 7.- Comparison of total-drag data for test bodies.

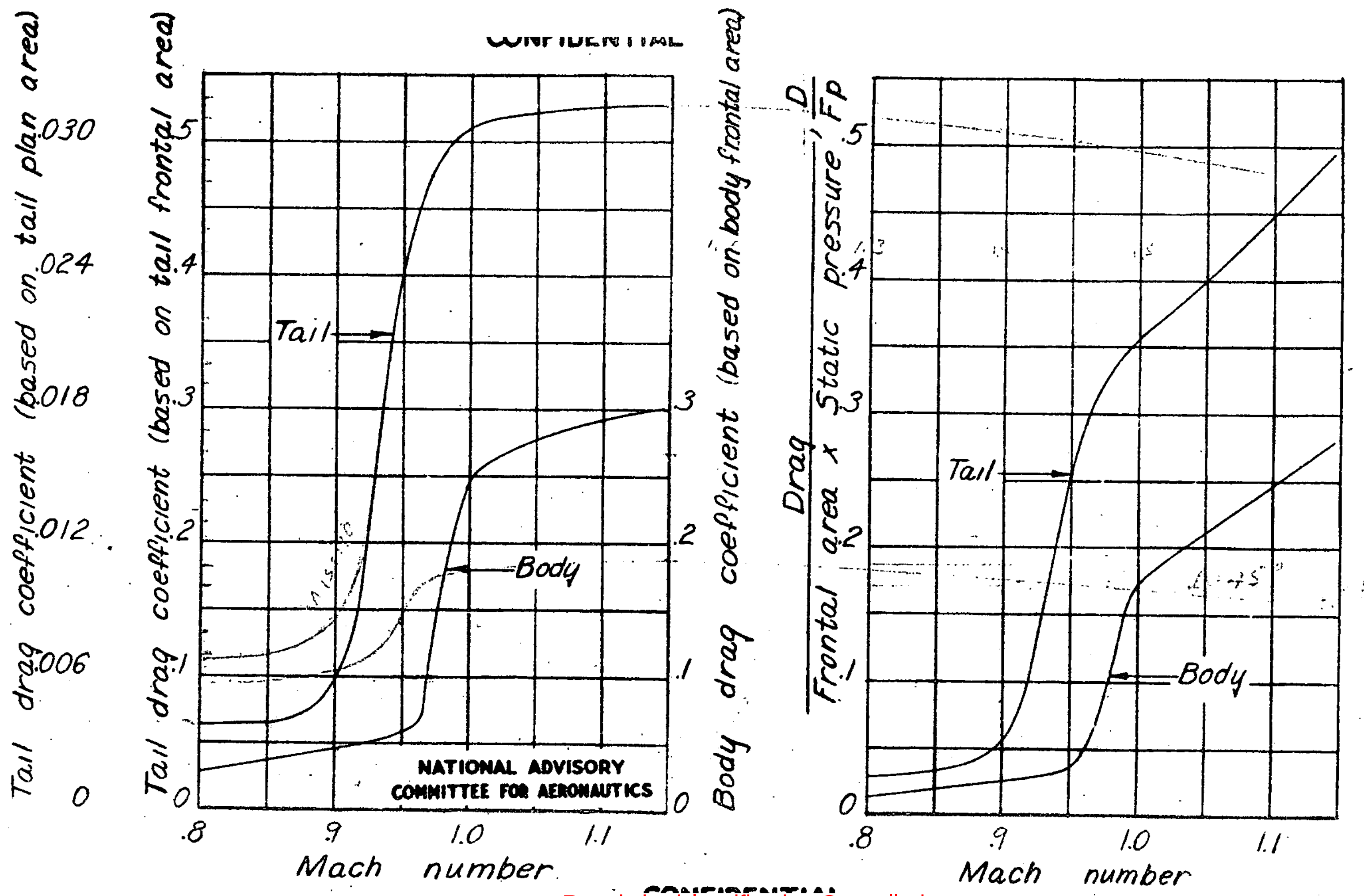

Figure 8. - Variations of body and tail drag coefficients and ratio D/Fp with Mach number. Curves represent average values for two telemeter-equipped bodies.